# CHAPTER 7
# GEOPHYSICAL INVESTIGATIONS FOR UNEXPLODED ORDNANCE (UXO)

7-1. Introduction. This chapter addresses the planning and performance of geophysical investigations at UXO sites. An overview of geophysical approaches, their capabilities and limitations is provided. Attachment 7-1 is a checklist for the project team to follow when planning geophysical investigations for UXO.

7-2. Objective.

a. Geophysical investigations are performed at UXO sites for one of three main purposes:

(1) Geophysical Sampling. Geophysical sampling is performed at representative portions of a site in order to characterize a larger area. The objective of geophysical sampling is to cost-effectively characterize the distribution, type and condition of UXO across a site.

(2) Geophysical Mapping. Geophysical mapping is performed across an entire area suspected of containing UXO. The objective of geophysical mapping is to locate all detectable UXO meeting pre-selected criteria such as UXO type, size, composition, depth or other similar parameters.

(3) Geophysical Interrogation. Geophysical interrogation can be performed at specific locations or small sites in order to obtain additional target information beyond that gathered by initial investigations. Techniques used for geophysical interrogation are generally too slow and expensive to be used over broad areas, but can yield important information about size, depth, composition and configuration of individual targets or target clusters.

b. In each case, the objective of the geophysical investigation is to efficiently locate buried UXO while minimizing the number of non-UXO geophysical anomalies.

7-3. Initial Geophysical Planning.

a. A geophysical investigation system capable of effectively locating buried UXO must have four fully integrated components, as follows:

(1) Experienced personnel - Personnel experienced with the theoretical and practical aspects of detecting relatively small UXO and discriminating the UXO from multiple non-UXO items that are also likely to be present. The selection and utilization of geophysical equipment is complex and requires qualified, experienced individuals. All geophysical investigations for UXO should be managed by a qualified geophysicist. A "qualified geophysicist" is a person with a degree in geophysics, geology, geological engineering, or closely related field and who has a minimum of five years of directly related geophysical experience.

(2) Geophysical instruments - Geophysical instruments that are well suited to detecting buried UXO, taking into account site specific factors that include type and depth of target UXO, as well as terrain, vegetation, geologic and cultural features.

(3) Analysis procedures - Procedures for analyzing and interpreting geophysical data generated by geophysical instruments.

(4) Navigational accuracy and precision - The ability to accurately and precisely locate a geophysical target in relation to other known points, preferably in a common survey grid and/or datum.

b. If any of the above four components are lacking, the overall geophysical system will not be able to locate UXO effectively. Therefore, it is important to carefully plan and integrate all aspects of a geophysical investigation and not start field work prematurely.

7-4. <u>Geophysical Instruments</u>. Detection and location of UXO primarily depends on the ability of geophysical instruments to distinguish the physical characteristics of UXO from those of the surrounding environment. The best currently available detection systems all detect the metallic content of the UXO, not the explosive filler.

a. Considerations that affect selection of an applicable UXO detection system include:

(1) UXO composition - Some detectors are limited to particular types of metals.

(2) UXO size - The larger the item, the deeper it can be detected.

(3) UXO depth - Some types of detectors are more effective than others when searching for deep items.

(4) UXO fuzing - Some detectors generate an electrical signal and should not be used around some fuzing systems.

(5) Background interference from metallic scrap - Metallic scrap, particularly UXO fragments co-mingled with UXO, interferes with geophysical instruments and makes UXO detection more difficult.

(6) Soil composition and geology - Natural soil and geologic conditions can affect geophysical instruments.

(7) Vegetation and terrain - In areas of difficult vegetation and terrain, more portable geophysical instruments are often necessary. In open areas, large towed-arrays may be a better choice.

(8) Cultural features - Overhead and underground utilities, fences, houses, nearby roads, radio/radar transmitters and similar cultural features can all adversely affect geophysical instruments.

b. Types of Instruments. Geophysical equipment can be divided into two broad classes of instruments: active and passive. Active instruments emit an electromagnetic or other signal and measure the effect. The active instruments most commonly used for UXO detection are conductivity meters. Passive instruments measure existing electromagnetic fields and the fluctuations within those fields. Passive instruments commonly used to detect OE include all types of magnetometers and gradiometers. Table 7.1 presents examples of geophysical detection technologies.

(1) Magnetometers. Magnetometers were one of the first tools used for locating buried munitions and remain one of the best. Most bombs and gun shells contain iron. When such munitions are illuminated by the Earth’s magnetic field, a disturbance in the field is generated which magnetometers detect. Some magnetometers use two magnetic sensors configured to measure the difference over a fixed distance of the magnetic field, rather than the absolute magnetic field, and are called gradiometers. Since magnetometers respond to ferro-magnetic metals, they should not be used to try to detect UXO that does not have a significant ferro-magnetic metallic content. In addition, magnetometers are sensitive to many iron-bearing minerals and "hot-rocks" which sometimes causes a high "false-positive" count. Currently, two types of magnetometers and gradiometers are most often used to detect buried munitions.

(a) Fluxgate Magnetometers. Fluxgate magnetometers are inexpensive, reliable, rugged, and have low energy consumption. Fluxgate magnetometers have long been a standard tool of EOD Units for a quick, inexpensive field reconnaissance of a site containing ferrous munitions.

(b) Optically Pumped Atomic Magnetometers. Optically pumped atomic magnetometers (also called atomic magnetometers or cesium-vapor magnetometers) utilize digital technology and are more expensive than fluxgate instruments. However, their high sensitivity, speed of operation, and high quality digital signal output make them a good choice for situations where digital data or digital post-processing is required.

(2) Conductivity Meters. Conductivity meters are electromagnetic induction instruments. They work by pulsing a small electrical current into the ground and measuring the induced electrical eddy currents that develop around metallic objects. They differ from magnetometers in that they are not limited to detecting ferrous items; they can detect any conductive metal. In addition, conductivity meters are usually less affected by geologic noise than magnetometers. There are numerous types of conductivity meters available; however, two are most commonly used in the search for UXO: time domain electromagnetic conductivity meters and frequency domain electromagnetic conductivity meters.

Table 7.1
Geophysical Detection Technologies
As of January 2000

| Technology | Effectiveness | Implementability | Cost | Representative Instruments | Notes |
|---|---|---|---|---|---|
| Flux-Gate Magnetometer | Medium: Flux-gate mags have been used as the primary detector in some highly ranked systems. | High: Flux-gate mags are light and compact. They can be used in any transversable terrain. Instruments are widely available from a variety of sources. | Less than average in typical terrain. | Schonstedt 52-CX<br>Schonstedt 72-CX | The analog output is not usually co-registered with navigational data. |
| Cesium Vapor (CV) Magnetometer | High: CV mags have been used in several highly ranked geophysical systems. Detects ferrous objects only. | Medium: CV mags are relatively light and compact. They can be easily used in open areas. In areas of difficult terrain or vegetation, it is difficult to maintain a correct navigational fix. CV mags are widely available from a variety of sources. | Average in typical terrain. Much below average when towed arrays can be used. | Geometrics G-858<br>Geometrics G-822<br>Scintrex Smart Mag | Digital signal should be co-registered with navigational data for best results. |

Table 7.1
Geophysical Detection Technologies
As of January 2000
(Continued)

| Technology | Effectiveness | Implementability | Cost | Representative Instruments | Notes |
|---|---|---|---|---|---|
| Time-Domain (TD) Electromagnetic Metal Detectors | High: TD electromag-netics have been used in several highly ranked systems. Detects both ferrous and non-ferrous metallic objects. | Medium: These instruments typically utilize a transceiver coil 1 meter square; small versions are also available. It is easy to use the instrument in open areas but difficult to use it in areas of difficult vegetation or terrain. The most commonly used instrument is widely available. | Average in typical terrain. Below average when towed arrays can be used. | Geonics EM 61 Geonics EM 61-hh | Digital signal should be co-registered with navigational data for best results. |
| Frequency-Domain (FD) Metal Detectors | FD electromag-netics have not been the primary detector in any highly ranked systems. (continued on the next page) | High: Mine/coin detectors are light and compact. They can be used in any traversable terrain. Instruments are widely available from a variety of sources. | Higher than average cost in typical terrain. Instruments are slow and can detect very small items. | Scheibbel ANPSS- 12<br>White All Metals Detector<br>Fisher 1266X Garrett | The analog output is not usually co-registered with navigational data. |

Table 7.1
Geophysical Detection Technologies
As of January 2000
(Continued)

| Technology | Effectiveness | Implementability | Cost | Representative Instruments | Notes |
|---|---|---|---|---|---|
| Frequency Domain Electromagnetic Metal Detectors (continued) | Other experience shows that they are very good at detecting small items. They are not good at detecting for deeply buried, single items. Detect ferrous and non-ferrous metallic objects. | | | | |
| Multifrequency Electromagnetic Metal Detectors | Medium: The GEM 2/3 was a primary detector in two highly ranked systems. However, they were never the highest ranked systems. Detects both ferrous and non-ferrous metallic objects. | Medium: These instruments are relatively light and compact and can be easily used in open areas. In areas of difficult terrain or vegetation it is difficult to maintain a correct navigational fix. Only a limited number of instruments are available. | Average in typical terrain. | GEM 2<br>GEM 3 | Digital signal should be co-registered with navigational data for best results. |

Table 7.1
Geophysical Detection Technologies
As of January 2000
(Continued)

| Technology | Effectiveness | Implementability | Cost | Representative Instruments | Notes |
|---|---|---|---|---|---|
| Ground Penetrating Radar | Low: Although a number of systems utilized ground penetrating radar as a detector, GPR was never successful as a stand-alone system. Detects both metallic and non-metallic objects. | Low: These instruments are large, bulky, and slow. They are difficult to use in any but the easiest terrain. Instruments are widely available from a variety of sources. | Much higher than average. Systems are slow and expensive. | GSSI SIR2, SIR3, SIR8, SIR10<br><br>Software & Sensors | The data output is usually viewed in transects, not maps. |

(a) Time Domain Electromagnetics (TDEM). Time domain electromagnetic conductivity meters work by pulsing an electrical signal into the ground several times a second. The transmitting coil is turned off between pulses and eddy current decay is then measured. Time domain conductivity meters provide an excellent compromise between detection depth and resolution. Such instruments provide a capability to locate all types of metallic munitions.

(b) Frequency Domain Electromagnetics (FDEM). Frequency domain electromagnetic conductivity meters work by transmitting a continuous electrical signal of one frequency into the ground and measuring resulting eddy currents of other frequencies. Some commercial frequency domain instruments are particularly useful for detecting large, deeply buried caches of munitions, and for detecting disturbed earth associated with pits and trenches. In addition, landmine detectors are FDEM instruments specifically designed for detecting very small, very close objects such as metallic firing pins in willow land mines. However, since the resolution ability decreases dramatically with depth, frequency domain conductivity meters are not optimum for detecting individual, deeply buried munitions. Most commercial coin detectors are frequency domain conductivity meters.

(3) Multiple Instrument Arrays. In cases where a particular geophysical instrument provides good detection results, multiple instruments can be joined in an array to achieve greater data density and greater production rates than possible with a single sensor system. However, due to access and mobility limitations, such arrays are generally limited to large, open areas.

(4) Analog Geophysical Mapping (Mag & Flag). This methodology is the traditional approach used to locate buried ordnance. Hand-held metal detectors (usually magnetometers) are used to map an area. Whenever the instrument detects an anomaly, the operator places a small flag in the ground. Mag & flag is particularly effective in areas where vegetation and terrain limit the use of larger digital systems. Also, mag & flag approaches should be used when there is insufficient difference between UXO at the site and other metallic frag and debris such that digital discrimination is ineffective.

7-5. UXO Detection Rates and Detection Depths.

a. Detection Rates in Test Plots. Geophysical instruments do not have specific ordnance detection rates. Detection rates are always site specific and are highly dependent upon the type of ordnance at the site, how the ordnance was used, how deeply it is buried, environmental conditions, geologic conditions, and cultural influences. During tests sponsored by the Army Environmental Center at Jefferson Proving Ground (JPG), the best munition detection rates of both ground-based conductivity meters and magnetometers were approximately 95 percent. In comparison, other systems tested at JPG that did not utilize either magnetometry or electromagnetics had extremely poor detection rates for buried ordnance.

b. Detection Rates in the Field.

(1) The true UXO detection rate at an actual field site can be hard to determine. Several factors can significantly reduce the effectiveness of a geophysical survey, including the following:

(a) Vegetation;

(b) Terrain;

(c) Geologic noise/gradients;

(d) Cultural noise (utilities, fences, etc.);

(e) UXO fragments; and

(f) UXO penetration beyond detection.

(2) These factors will reduce the actual achieved detection rate. However, since the true amount of UXO at a site is unknown, the detection rate, based upon items recovered, is also

unknown. Actual detection rates are typically between 70 to 90 percent of UXO present, even when the best available technology is applied.

c. Detection Depths.

(1) The general rule is, the larger the UXO, the deeper it can be detected. Based upon the work at JPG and other sites, the typical maximum detection depth for various UXO can be estimated as a function of diameter of the object. This empirical formula will provide an initial estimate of how deeply a UXO can be detected, provided proper instruments and procedures are utilized. The formulas for estimating maximum detection depth are presented in Table 7.2.

Table 7.2
Maximum Detection Depth Estimating Formulas

| |
|---|
| $\log(d) = 1.354 \log(dia) - 2.655$ (mag)<br>$\log(d) = 1.002 \log(dia) - 1.961$ (EM) |
| *Notes:*<br>*d = actual depth to top of buried UXO, in meters.*<br>*dia = diameter of minor axis of UXO, in millimeters.*<br>"d" corresponds to the required clearance depth for that particular location on the project site and UXO "dia" is diameter of the minimum size item, as determined by the project team, that the geophysical investigation is responsible for detecting. |

(2) The formulas in Table 7.2 were used to develop the Maximum Detection Depth data presented in Table 7.3. There are many site-specific factors that can affect detection depth. Therefore, Table 7.2 and Table 7.3 should be considered as guidance, not an absolute.

d. Penetration Depths. The maximum possible depth of UXO is an important consideration in the selection of an appropriate detection system. If UXO is intentionally buried, factors affecting burial depth may include type of soil, mechanical vs. hand-excavation, depth of water table, etc. If the munition was fired or dropped, then the depth of penetration can be estimated by considering soil type, munition type and weight, and impact velocity. There are many cases where UXO can penetrate deeper than geophysical instruments can currently reliably detect. On such sites, it is possible that undetected UXO remains deeper than it can be detected. Figure 7-1 shows the depth of recovery for thousands of OE items. The curve indicates that while the maximum depth of penetration of UXO will resemble the depth predicted in the penetration analysis, the actual depth of penetration for most items is much lower. In fact, most items were located less than two feet deep.

Table 7.3
Ordnance Penetration/Detection

| Ordnance Item | Depth of Penetration (ft)[1,2] | | | Typical Max Detection Depth[4] (ft) | |
|---|---|---|---|---|---|
| | Sand | Loam | Clay | Magnetometry | TDEM[5] |
| 14.5 mm Trainer/Spotter, M1813A1 | 0.2 | 0.3 | 0.4 | 0.3 | 0.5 |
| 20mm, M56A4 | 2.3 | 3.0 | 4.6 | 0.4 | 0.7 |
| 22 mm Subcal for 81 mm mortar | 1.4 | 1.9 | 2.8 | 0.5 | 0.8 |
| 35 mm Subcal M73 | 0.5 | 0.7 | 1.0 | 0.9 | 1.3 |
| 37 mm, M63 | 3.9 | 5.2 | 7.9 | 1.0 | 1.3 |
| 40 mm, M822 (AA) | 2.3 | 3.0 | 4.5 | 1.1 | 1.4 |
| 40 mm, M677 (Mk 19) | 0.2 | 0.3 | 0.4 | 1.1 | 1.4 |
| 40 mm, M381 (M203/M79) | 0.2 | 0.3 | 0.4 | 1.1 | 1.4 |
| Mk 118 Bomblet | 1.9 | 2.4 | 3.7 | 1.5 | 1.8 |
| Mk 23 3 lb. Practice Bomb | 2.7 | 3.5 | 5.4 | 1.7 | 2.0 |
| 57 mm, M306A1 | 2.7 | 3.6 | 5.5 | 1.7 | 2.0 |
| M9 Rifle Grenade | 0.1 | 0.2 | 0.2 | 1.7 | 2.0 |
| 2.25” Rocket, Mk 4 | 4.0 | 5.2 | 8.0 | 1.7 | 2.0 |
| 60 mm, M49A1 (charge 4) | 1.1 | 1.5 | 2.3 | 1.9 | 2.2 |
| 2.36” Rocket, M6A1 | 0.4 | 0.5 | 0.8 | 1.9 | 2.2 |
| 66 mm, M72 LAW | 0.9 | 1.2 | 1.8 | 2.1 | 2.4 |
| 66 mm TPA, M74 | 0.7 | 0.9 | 1.4 | 2.1 | 2.4 |
| BLU-3/B,-27/B,-28/B | 2.2 | 2.9 | 4.4 | 2.3 | 2.5 |
| 2.75” Rocket, Practice | 8.1 | 10.7 | 16.3 | 2.3 | 2.5 |
| 6 lb. Incendiary Bomb | 3.4 | 4.4 | 6.7 | 2.4 | 2.6 |
| 75 mm, M48 | 4.9 | 6.4 | 9.8 | 2.5 | 2.7 |
| 75 mm, M310 | 3.9 | 5.1 | 7.8 | 2.5 | 2.7 |
| 81 mm, M43A1 (charge 8) | 2.7 | 3.5 | 5.4 | 2.8 | 2.9 |
| 83 mm SMAW Mk 3 | 2.8 | 3.6 | 5.6 | 2.9 | 3.0 |

Table 7.3
Ordnance Penetration/Detection
(Continued)

| Ordnance Item | Depth of Penetration (ft)[1,2] | | | Typical Max Detection Depth[4] (ft) | |
|---|---|---|---|---|---|
| | Sand | Loam | Clay | Magnetometry | TDEM[5] |
| 84 mm, M136 (AT4) | 2.5 | 3.7 | 5.0 | 2.9 | 3.0 |
| 3.5” Rocket, M28 | 0.8 | 1.1 | 1.7 | 3.2 | 3.2 |
| 90 mm, M371A1 | 2.0 | 2.7 | 4.1 | 3.2 | 3.2 |
| 25 lb. Frag Bomb[3] | 2.1 | 2.8 | 4.3 | 3.2 | 3.2 |
| AN-M41A1 20 lb. Practice Bomb | 5.0 | 6.6 | 10.0 | 3.3 | 3.3 |
| 105 mm, M1 (charge 7) | 7.7 | 10.1 | 15.4 | 4.0 | 3.8 |
| 106 mm, M344A1 | 6.5 | 8.5 | 13.0 | 4.0 | 3.8 |
| 4.2” Mortar, M3 (max charge) | 4.1 | 5.4 | 8.3 | 4.1 | 3.9 |
| Dragon Guided Missile | 0.9 | 1.1 | 1.7 | 4.3 | 4.0 |
| 155 mm, M107 | 14.0 | 16.4 | 28.0 | 6.7 | 5.6 |
| 8”, M106 (charge 8) | 16.4 | 24.2 | 36.9 | 9.7 | 7.3 |
| M38A2 100 lb. Practice Bomb | 8.6 | 11.3 | 15.2 | 9.9 | 7.4 |

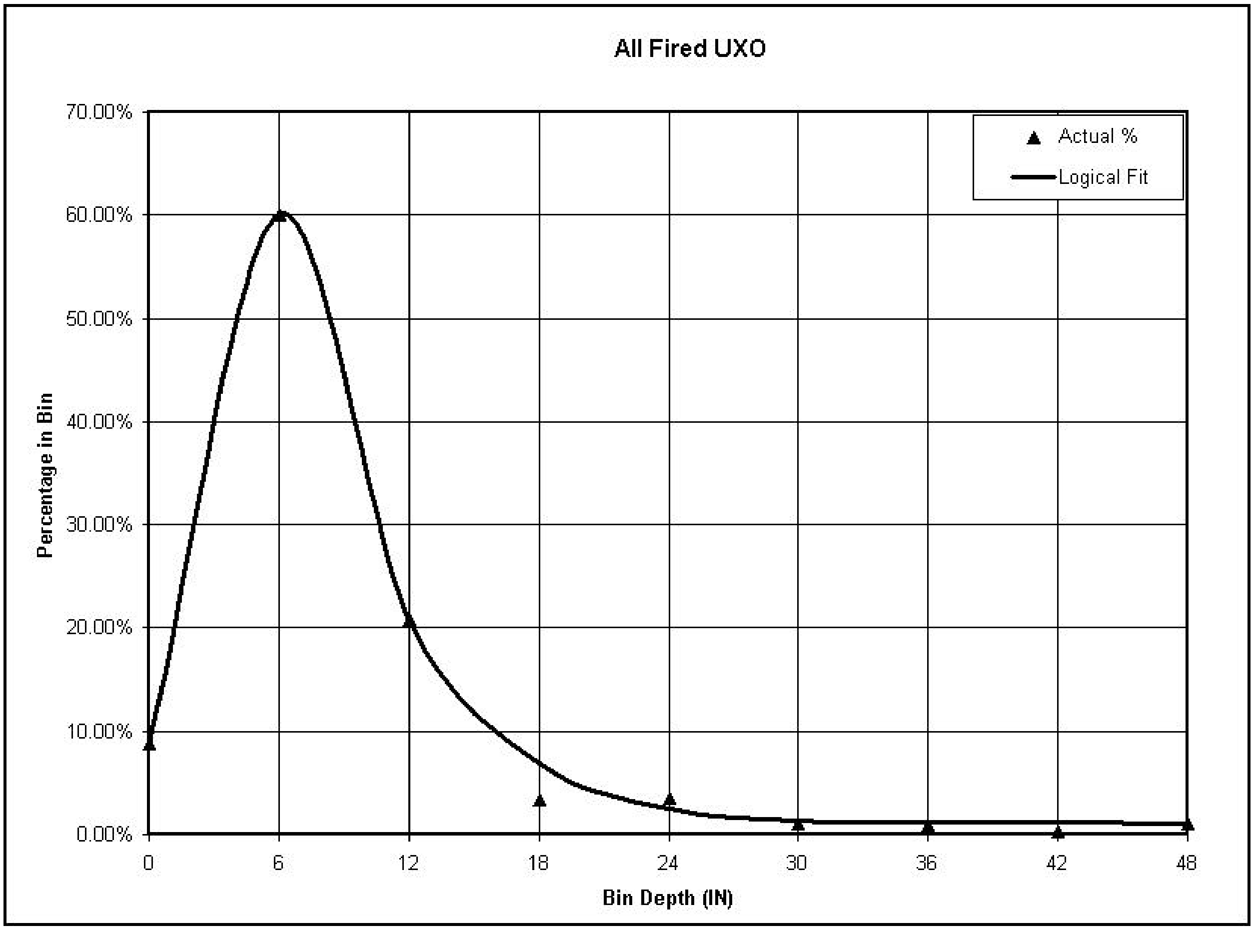
[1]Penetration depths include the following “worst-case” conditions assumptions: impact velocity is equal to maximum velocity of round; impact is perpendicular to ground surface; munition decelerates subsurface in a straight line; munition does not deform upon impact. Typical penetration depth for any individual item will usually be significantly less.

[2]Actual detection depth may vary based on field conditions and be either lower or deeper.

[3]All bombs are assumed to have an impact velocity of 1135 feet per second.

[4]Maximum depth of penetration assuming a velocity of 500 fps.

[5]Time Domain Electromagnetics
Rev 1-5/11/99




Note: The database used to develop this graph was populated predominantly with UXO items typically used by or in close support of ground troops. Large naval ordnance and large aerial bombs are under-represented.

Figure 7-1
Actual Depth of Recovery of Fired UXO

7-6. Geophysical Instruments and Electric Fuze Safety. Some electric fuzing systems used in munitions are sensitive to certain electromagnetic frequencies. Although the probability is very low, such signals have the potential for causing sensitive munitions to detonate. This fact should be considered when planning geophysical investigations at munitions sites. The following safety precautions and safety recommendations are applicable on all OE projects:

a. Magnetometers and gradiometers are passive instruments that are not designed to introduce electrical energy into the ground. Therefore, passive magnetometers and gradiometers may be used at all OE sites in accordance with manufacturer's instructions.

b. Active instruments (including but not limited to mine and coin detectors, frequency-domain electromagnetic detectors and time-domain electromagnetic detectors) are designed to introduce electrical energy into the ground. Prior to any such systems being used at an OE site, the instrument operator must determine if fuzing systems containing electrical components are reasonably expected to exist at the site.

c. Active instruments may be used in accordance with manufacturer's instructions at OE sites not containing electrical fuzes.

d. Active instruments may not be used at OE sites where fuzing systems containing electrical components are reasonably expected to exist, unless a waiver is granted by the Design Center Safety Manager. The instrument operator must submit a request for waiver accompanied by a written hazard analysis documenting the need for use of the active instrument, the manner in which the instrument will be used, the power output of the instrument, a description of the electrical fuze system(s) anticipated at the site, the estimated risk of fuze detonation, and the consequences of such a detonation, were it to occur. Waivers may be granted on a case-by-case basis.

7-7. Analysis Software. There are many software packages that can be used to evaluate geophysical data. Often the geophysical equipment manufacturers provide specialized software for specific instruments. This software is primarily used to transfer the data from the instrument to the computer and perform corrections to the data. Corrections such as navigation adjustments and rotation and translation of coordinate systems are necessary before analyzing the data. The corrected data is then transferred into a software package designed to facilitate contouring, mapping and selection of anomalous data potentially representing UXO.

7-8. Navigation.

a. Navigation Systems. Positional precision and accuracy is a requirement for geophysical investigations at UXO sites. Since detection and removal of buried UXO is a multi-stage process, it is important that positional information gathered at one stage be useable at the next stage. This means that all data collected at each stage must be tied to a common positional system. The positional system can be either temporary (i.e., temporary monuments, landmarks, etc.) or permanent (i.e., standard reference survey grid, tied to permanent monuments). In actual practice, the use of temporary or assumed location systems on UXO projects is strongly discouraged. It is often difficult or impossible to register multiple temporary location systems to a common reference point after the fact. As a result, true locations of work performed become unrecoverable. U.S. Army Engineering and Support Center, Huntsville (USAESCH) recommends that all navigation be based on the local State Grid Plane system.

b. Positional Accuracy and Precision.

(1) Mag & Flag. The most typical geophysical survey technique in ordnance related surveys is “mag and flag”. In these types of surveys, anomalies are selected by instrument response and flagged immediately in the field. The disadvantage of this technique is that without recorded data, there is no opportunity to revisit the data for additional interpretation or analysis at a later time.

(2) Digital Geophysics. More recently, magnetic and electromagnetic instruments have been combined with a ground based grid system to track the positions of collected data and to create a map of the survey. The grid system commonly involves utilizing a surveyor to set up rectangular or square grids having dimensions from ten to several hundred feet on a side. The geophysicist tracks his/her position in the grid by collecting data in a straight line from one edge of the grid to the other. The distance traveled along each linear traverse is usually calculated using either a distance tracking system, such as a wheel based unit which records distance traveled along with data collected, or by a constant pace method. The constant pace method assumes that the survey is being performed at a constant rate of speed and the time during which the survey is performed is divided by the actual distance traveled to determine the locations of specific data points. Marks are often inserted manually at specified distances by the geophysicist in each of these methods to assist in the positional accuracy.

7-9. Site Preparation and Vegetation Removal.

a. UXO Safety. Site preparation for geophysical investigations at UXO sites can be a significant issue. The first issue to be considered is the presence of surface UXO. Sites must be cleared of dangerous surface UXO prior to initiating subsurface geophysical investigations.

b. Vegetation and Obstacle Removal. There are no currently available "stand-off" sensors that can consistently detect buried UXO. All geophysical instruments currently in use to detect UXO must traverse directly over every square foot of area investigated, and as close to the ground surface as feasible. Airborne systems, even those only a few feet above ground surface, do not work. Therefore, in order to efficiently detect the maximum amount of buried UXO at a site, most or all surface vegetation and other obstacles must be removed. This may be acceptable for small sites, or sites already having only limited vegetation, but is generally unacceptable for larger sites. Also, at many sites it is environmentally unacceptable to cut down, burn away or otherwise remove the vegetation.

c. Terrain. Site terrain can limit the effectiveness of geophysical investigations for UXO. Very steep or rugged areas can be hazardous for geophysical investigation teams. In such cases, it is often best to use a mag & flag approach. Likewise, swampy areas present serious difficulties to geophysical investigation teams.

7-10. Geophysical Prove-out. The following paragraphs describe the project team's responsibilities during the instrument prove-out. It should be noted that the geophysical prove-out may be a complex, time-consuming effort.

a. Data Quality Objectives for Prove-out. When designing a geophysical prove-out plot care must be taken to identify DQOs. The prove-out plot must resemble the actual field site both in physical characteristics and in the UXO buried within it. The primary purposes of a prove-out plot include the following:

(1) To determine if a particular approach will work at a particular site. There are geologic, terrain and other differences that can cause proven geophysical approaches to not work at particular sites.

(2) To determine the optimum geophysical approach for a particular site. All geophysical approaches have inherent strengths and weaknesses. Very seldom will one instrument or approach have the best absolute detection rate, the lowest false alarm rate, the highest production rate, and the lowest cost. Test plots provide information used to select an optimum geophysical approach.

(3) To demonstrate detection depth capabilities. Team members and stakeholders often need site-specific data demonstrating detection depth. When a removal action is performed without a test plot, there may be little information to support the true depth of detection. A test plot, with target items buried at multiple depths, provides important information regarding depth and quality of clearance.

(4) To assure contractor compliance with the contract. Test plots provide a safe area for the geophysical investigation team to develop site-specific field and evaluation procedures necessary to demonstrate compliance with project requirements.

(5) Evaluate the project team's data collection, data transfer quality and data quality control method(s), and data transfer rates.

b. Prove-Out Work Plan. The first step of performing a geophysical prove-out is to develop a prove-out work plan. In the plan it is necessary to state the prove-out objectives and to describe how these objectives will be met. The elements described in the following sections should be addressed.

(1) Prove-Out Grid Location and Construction. Selection of the prove-out grid or grids should be based upon the technical and site-specific considerations developed and finalized during the initial project site visit. Factors to be considered include the following:

(a) Similarity of terrain, vegetation, and geologic conditions to actual field site;

(b) Proximity to field site;

(c) Isolation from overhead power lines, radio transmitters, underground utilities, etc;

(d) Convenient access;

(e) Likelihood that the area will be disturbed during period of use;

(f) Rights-of-Entry; and

(g) Possibility of pre-existing buried UXO.

(2) Pre-Seeding Geophysical Mapping. After a site has been selected and the surface prepared, a pre-seeding geophysical survey should be performed in order to determine and document base-line geophysical conditions at the site.

(a) Size and Configuration. Each plot is unique, but for sites where a significant amount of geophysical mapping is anticipated, a test plot of one-quarter acre to one acre in size with 20 to 50 separate buried items, would be typical. For sites with limited geophysical mapping, much smaller and less complex plots should be considered. Test plots need not be square; they can be any convenient shape.

(b) Survey Accuracy. Survey accuracy of the test plot corners and of all items buried in the test plot, should be to the nearest 0.1 ft.

(c) Layout. Test plots should have an area designated as a "known" area. The geophysical mapping team should be provided all pertinent information about the "known" area so that they can optimize their equipment and procedures. Once appropriate procedures are developed for the "known" area, the geophysical mapping team should proceed to the "unknown" area, perform geophysical mapping, and make predictions.

(d) Seeded Items. A listing of probable munitions items to be seeded in the grid must be developed. Historical records, such as the ASR, should be consulted and used to develop a list of items of interest. After the list is developed, sources of inert items must be determined. It is preferable that inert UXO be utilized in the prove-out grid. However, due to the difficulty in locating and transporting such items, it will often be necessary to manufacture surrogate items of approximately the same composition, size and shape for use in the test plot. In many cases, multiple UXO have been utilized at an area and it will not be feasible to duplicate all of them. In such cases the geophysicist and UXO specialist should work together to determine when different UXO may be consolidated into one class for prove-out purposes

(e) Depths and Orientation. One major objective of a prove-out plot is to demonstrate the depth of detection of various UXO. In order to accomplish this, the UXO must be buried at various depths and orientations. There is seldom a reason to bury the UXO either excessively shallow or deep. Rather, the UXO should be buried in the proximity of the boundary between the detect zone and no-detect zone for items that size, as shown on Figure 7-2. The orientation of the item will also affect delectability. In general, duplicate items should be buried in an E-W orientation, a N-S orientation, and an up-down orientation, at each depth studied. The number of seeded items should be sufficient to provide a representative sampling of probable munitions (type, condition, and depth) and statistically support probability of detection calculations. The number, orientation, and depths of the OE items will be sufficient to characterize the limitations of the proposed geophysical equipment and to evaluate the ability of the proposed geophysical equipment to locate each type of OE at the anticipated depths. After the target items are buried, care should be taken to blend excavation locations back to natural conditions.

(f) Cultural Interference. Some field sites will have significant cultural interference. In such cases, consideration should be given to duplicating that interference in the test plot.

(g) UXO Fragment Interference. At most impact areas there are many more pieces of UXO metallic fragments (frag) than there are UXO. This frag often results in a serious degradation in the capability of the geophysical instruments to detect UXO. In such cases, consideration should be given to duplicating the effects of frag in the test plot, either through the use of artificially placed frag or by the establishment of the test plot in an area containing frag.

(3) Data Collection Variables. It is important to collect and analyze test plot data using the same equipment, personnel and procedures that are planned for field use. Multiple geophysical surveys using each proposed geophysical instrument will be performed. Geophysical instrumentation standardization will be completed prior to and upon completion of each prove-out grid to characterize system operation. When collecting data for a prove-out, the following elements are subject to modification and evaluation. It will not be necessary to evaluate every factor at every site. The project team must determine the elements to be evaluated for a particular project:

(a) Instrument Height. The height of the detection portion of the instrument can be modified. Generally speaking, the closer the detector is to the UXO, the more pronounced the

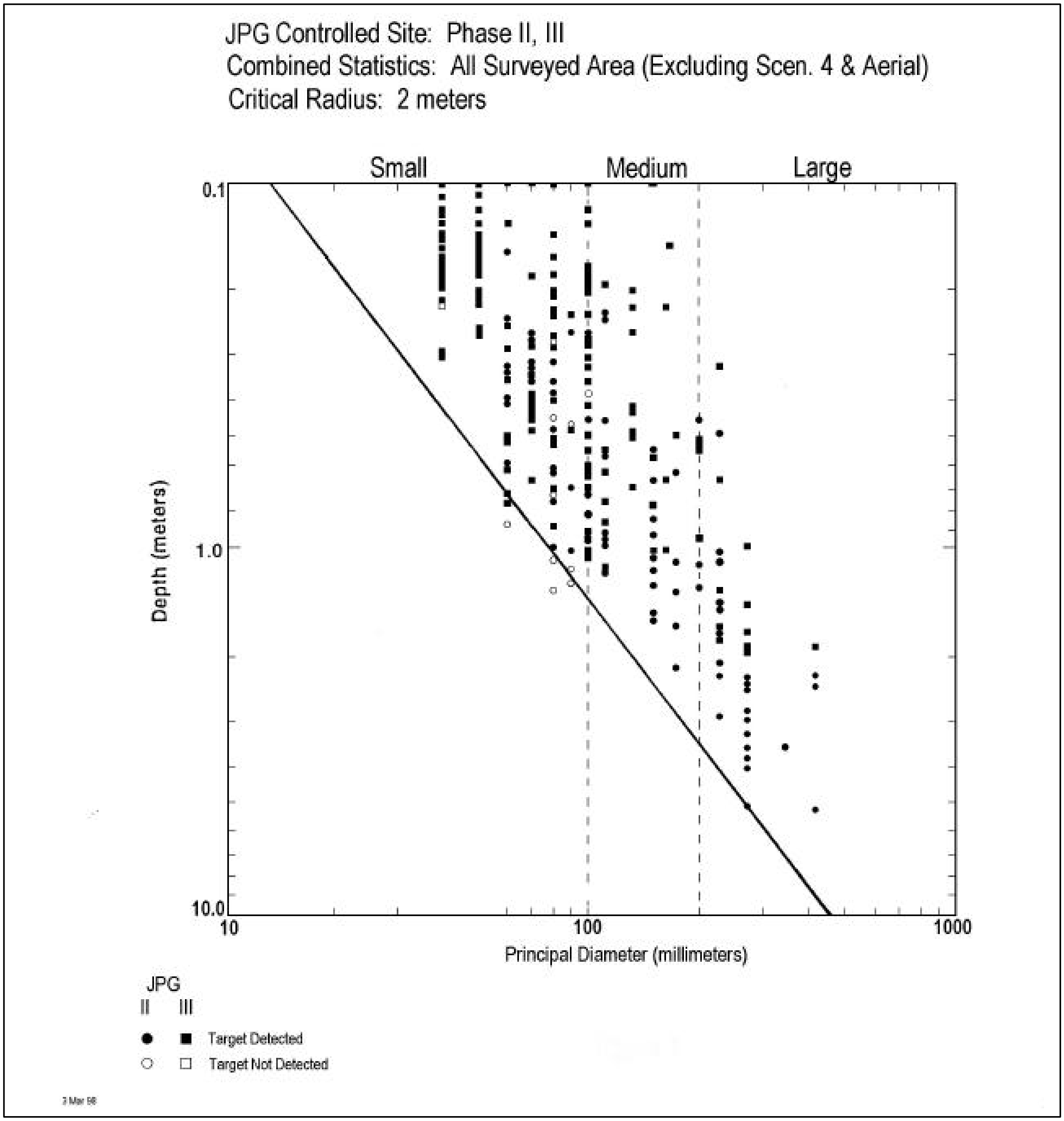



Figure 7-2
UXO Detection at Jefferson Proving Ground

instrument response will be. When the intended target is small, it may be beneficial to move the detector closer to the ground. On the other hand, if the intended target is large, it might be beneficial to raise the detector in order to minimize the influence of small items.

(b) Instrument Orientation and Direction of Travel. Instrument orientation and direction of travel can have a pronounced effect, particularly with magnetometry. A magnetometer can measure different values over a single location, depending on direction of travel and orientation. When precise surveys are being performed it is necessary to add a "heading correction" to each data point in order to account for this variation.

(c) Measurement Interval. Instrument readings should be collected at one-foot intervals or less.

(d) Lane Width. Lane width may be modified depending on the size of the intended UXO. For large items, a lane width of five (5.0) feet, or larger, is acceptable. For small items, lane widths of only one (1.0) foot may be necessary.

(4) Data Analysis and Interpretation. The ability to analyze and interpret the geophysical data collected at the prove-out grid will be demonstrated by the project team using the methods of its choice. The data collected at the prove-out grid from each geophysical instrument will be post-processed and analyzed. A final listing of selected target anomalies will be prepared and provided to the project team for comparison with seeded item locations.

(5) Data Evaluation.

(a) The geophysical data must be evaluated and scored so that the different geophysical approaches can be compared and ranked. Scoring criteria should include, as a minimum, the following: probability of detection (Pd); probability of false alarm (Pfa); production rate; cost per unit area; equipment durability and safety.

(b) No single geophysical system is likely to achieve maximum scores in all evaluated areas. Therefore, the evaluation team must determine which approach is likely to be most efficient for the site.

(6) Selection of Detection Instruments. The project team, based upon experiences at other project sites containing similar geophysical considerations, will nominate instruments for consideration. The project team will review its letter report describing proposed geophysical equipment, techniques, and methodologies. The letter report should also contain sufficient supporting information to justify the project team’s recommendations, including manufacturer specifications for recommended geophysical equipment and a definition of the expected target anomalies based upon the ASR or EE/CA.

7-11. Geophysical Investigation Plan. Prior to initiating field activities, a Geophysical Investigation Plan should be prepared. This Plan, which is a subsection of the Work Plan, is prepared to describe the project requirements for all geophysical activities that will take place during an OE project. The Geophysical Investigation Plan will include a justification for the proposal of the geophysical instrumentation, methodology, and prove-out. The proposed goals, methods, and procedures will be tailored to anticipated site conditions and technical requirements as well as applicable safety and security regulations. The Geophysical Investigation Plan must include procedures for a geophysical instrument prove-out, if not previously completed.

a. Contents. The project team member reviewing the Geophysical Investigation Plan should ensure that the following elements are addressed:

(1) Geophysical investigation methods:

(a) Equipment;

(b) Procedures;

(c) Personnel;

(d) Production rates;

(e) Data resolution, or line/grid width requirements;

(f) Data density; and

(g) Data processing.

(2) Location surveying, mapping and navigation:

(a) System description; and

(b) If GPS systems are used, correlate satellite availability with work/rest periods.

(3) Instrument standardization:

(a) Instrument drift (DC offset);

(b) Standardization procedures;

(c) Abbreviated standardization checks; and

(d) Instrument response to a known standard.

(4) Data processing, correction and analysis:

(a) Instrument drift correction;

(b) Diurnal drift correction;

(c) Digital filtering and enhancement; and

(d) Correlation with ground truth.

(5) Quantitative interpretation and dig sheet development.

(6) Anomaly reacquisition.

(7) Feed-back process (Comparison of dig-sheet predictions with ground-truth).

(8) Quality control.

(9) Corrective measures.

(10) Records management.

(11) Interim reporting.

(12) Final reports and maps.

b. Geophysical Investigation Plan Review and Approval. The Geophysical Investigation Plan, a component of the Work Plan, will be submitted to the PM and Design Center POC. The Design Center POC will route the plan to the appropriate USACE technical staff for review, comment and approval. Once approved by the Design Center and CO, the Geophysical Investigation Plan represents the standard to which all geophysical activities are compared to assure compliance during the project.

7-12. Geophysical Sampling.

a. Pre-Sampling Studies. When planning geophysical investigations for UXO at current and former military installations, it is necessary to determine the limits of the area to be investigated. Military installations are often extremely large and not all areas are likely to have buried UXO. The ASR, historical aerial photographs, range-control records, facility engineering and master planning documents, personnel interviews, and other pertinent documents should be carefully evaluated in order to locate evidence of how, when and where munitions might have been used at a site.

b. Sectorization.

(1) Once the review of historical documents has been accomplished, the site must be sectorized. Sectorization is the process by which large, non-homogenous areas of a military installation are subdivided into smaller, more homogenous areas. When defining sectors, the following factors should be considered:

(a) Former military use;

(b) Anticipated UXO type;

(c) Anticipated UXO distribution;

(d) Terrain and vegetation;

(e) Current land use; and

(f) Natural and cultural boundaries.

(2) Obviously, it is not possible to define a sector that is completely uniform and homogenous. However, the goal is to define sectors such that any necessary future OE response action can be applied to the entire sector. It should be noted that sectorization is an active process. As the project continues and more data is collected, it is likely that sector boundaries will need to be modified to reflect actual site conditions.

7-13. <u>Sampling Within a Sector</u>. When geophysically characterizing a sector, an initial decision must be made regarding where the geophysical investigations will occur. Basically, there are two choices: either investigate the entire sector, or sample a representative portion of the sector and infer the results across the whole. On relatively small sectors, it can be efficient in terms of cost, schedule, and environmental impact to geophysically map the entire area. However, large sites can present significant cost, schedule, access and environmental impact challenges that preclude geophysically mapping large areas as a method of site characterization. Various site sampling methodologies are discussed below.

a. 100% Sampling. Complete geophysical mapping is a good approach for small sites. At such sites the mobilization/demobilization and other fixed costs can be relatively high when compared to the actual mapping costs. In these cases, the most cost-effective approach might be to map the entire site. Such an approach is especially recommended for sites smaller than about 20 acres.

b. Authoritative Sampling. With authoritative sampling, an expert having knowledge of the site designates where and when samples are to be taken. This type of sampling should only be considered when the objectives of the investigation are not of a statistical nature. Generally, conclusions drawn from authoritative sampling apply only to the individual samples and aggregation may result in severe bias and erroneous conclusions.

c. Probability Sampling.

(1) When the study objectives involve estimation or decision making, some form of probability sampling is required. Probability sampling is sampling where every member of the target population has a known probability of being included in the sampling. This does not preclude use of an expert's knowledge of the site in designing a probability-based sampling plan; however, valid statistical inferences require that the plan incorporate some form of randomization in selecting the sampling locations. An efficient probability sampling design is one that uses all available existing information to stratify the region and set appropriate probabilities of selection. For example, probability sampling can take into consideration prior knowledge of areas with higher potential for UXO contamination (e.g., targets) by weighting such areas more heavily in the sample selection and data analysis.

(2) Probability sampling can be of various types, but all types use randomization, which allows valid probability statements to be made about the quality of estimates that are derived from the resultant data. USACE has developed a statistical process, known as UXO Calculator, to determine the amount of geophysical mapping necessary to characterize a homogenous sector of a UXO site. For a discussion of this methodology, refer to Chapter 10 of this manual. The statistical approach is designed to characterize "dispersed" UXO such as occurs at impact areas, bomb target areas, kick-out from open burn/open detonation operations, dispersal from munitions magazine explosions, and similar activities. It is not designed to statistically characterize activities that do not have random patterns, such as UXO intentionally buried, purposely hidden contraband munitions, and similar activities.

(3) The amount of necessary sampling within a sector is determined by USAESCH's UXO sampling protocols. The larger the sector, the smaller the percentage of sampling is required. UXO Calculator should be used on a site-specific basis to determine appropriate sampling percentages. However, Table 7.4 indicates the approximate amount of sampling (random plus directed) that should be anticipated.

(4) It should be remembered that mobilization/demobilization and other fixed costs can be relatively high when compared to total geophysical investigation costs at small sites. Therefore, at small sites it is often more cost-effective to geophysically investigate the entire site, rather than use statistical sampling.

Table 7.4
Typical Geophysical Sampling Requirements

| Sector Size, Acres | Required Minimum Area Investigated | Recommended Minimum Area Investigated |
|---|---|---|
| < 50 | 5.0% | 7.5% |
| 51 -100 | 3.0% | 4.5% |
| 101 - 150 | 2.0% | 3.0 % |
| 151 - 1000 | 1.0% | 1.5% |
| > 1000 | 0.5% | 0.75% |

(5) Probability sampling strategies include the following:

(a) Fixed Pattern Grid Sampling. Fixed-Pattern grid sampling is the process where grids are laid out in a pattern on a fixed percentage (often 10 percent) of a sector. Fixed pattern sampling is not normally used since other more random patterns can provide statistically valid results using fewer grids. An example of fixed pattern grid sampling is shown in Figure 7-3.

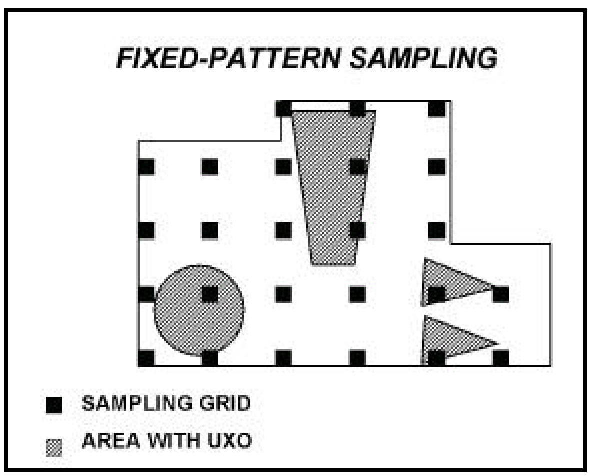



Figure 7-3
Fixed Pattern Grid Sampling

(b) Random Pattern Grid Sampling.

(1) Random pattern grid sampling uses a statistical approach to place grids randomly throughout a sector. The total area to be sampled is first determined using a statistical process, such as UXO Calculator. Then, grid size and shape is determined based on site terrain, vegetation, and the geophysical instruments to be used. Grids can be any convenient shape, but square or rectangular grids are the most common. Grids may be as small as 2,500 square feet or

as large as one hectare in size. Grids need not all be the same size. An example of random pattern grid sampling is shown in Figure 7-4.

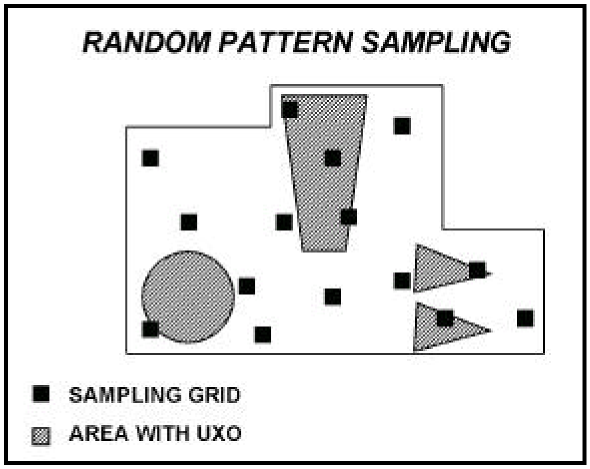



Figure 7-4
Random Pattern Grid Sampling

(2) Since in random pattern sampling grids are placed completely randomly, there can be large unsampled areas within a sector. Also, areas known to contain UXO might remain unsampled. For this reason, purely random pattern sampling is not recommended.

(c) Hybrid Sampling. In order to assure that a sector receives thorough sampling grid coverage, and that areas known or suspected to contain UXO are geophysically investigated, a modified version of random pattern sampling is recommended. In this hybrid approach, grids are placed randomly across the sector as described above. Afterwards however, approximately 20 percent more grids are placed in biased locations to fill any apparent data gaps. This approach is recommended when sampling grids are used. An example of hybrid sampling is shown in Figure 7-5.

(d) Transects. Geophysical investigation transects are another approach used to characterize sectors. Transects are also a good approach to determine boundaries of contaminated areas. When used for sector sampling, transects may simply be considered as very narrow, fixed pattern-grids. Transects are best utilized at sites with easy terrain and vegetation. An example of transect sampling is shown in Figure 7-6.

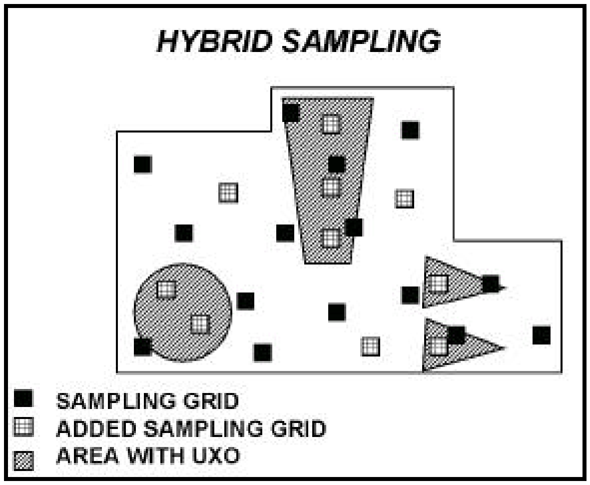



Figure 7-5
Hybrid Sampling

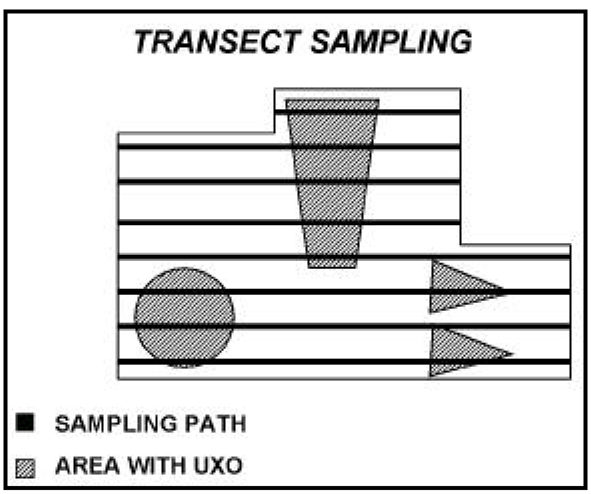



Figure 7-6
Transect Sampling

(e) Meandering Path Sampling. Meandering path sampling is a process where a geophysical investigation instrument is integrated with a navigation instrument, usually differential Global Positioning System (GPS), that links extremely accurate positional data with the geophysical readings. Then, a geophysical team "meanders" randomly throughout a site, until the total area geophysically mapped equals the area that would have been required if sampling grids were used. Afterwards, the geophysical data is analyzed, anomalies are located, then excavated and evaluated. Meandering path sampling offers large cost savings at sites with difficult vegetation and terrain since vegetation removal costs are virtually eliminated and surveying costs are greatly reduced. An example of meandering path sampling is shown in Figure 7-7.

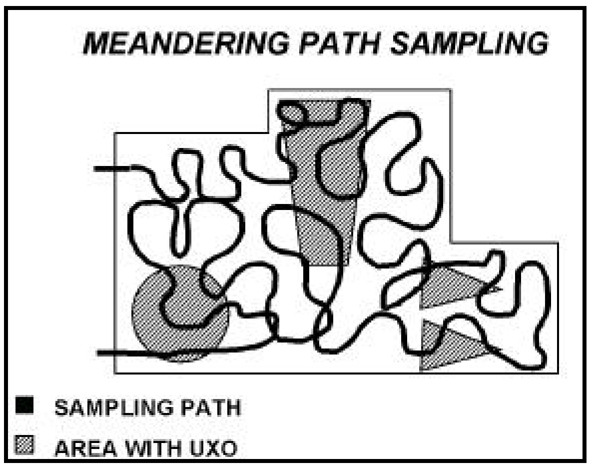



Figure 7-7
Meandering Path Sampling

7-14. Sampling Anomalies Within a Grid. After a grid or other area has been geophysically mapped, multiple "anomalies" are likely to have been located. For mag & flag projects, these anomalies will be marked as flags at the location of each subsurface anomaly. For projects where digital geophysical methods are used, the geophysicist will pick and evaluate anomalies with the help of analytical software. In either case, the anomalies must be excavated by qualified UXO personnel in order to determine if the anomaly represents a UXO or some other feature. On many grids, the number of anomalies will be manageable and all should be excavated in order to characterize the grid. However, on some sites, particularly those within impact areas, the number of anomalies may range from several dozen to several thousand anomalies per acre, most of which will be small metallic frag. When this occurs, statistical sampling of the grid may be necessary.

a. 100% Sampling. When there are, on average, fewer than approximately 20 anomalies per grid, all anomalies should be excavated and evaluated.

b. Statistical. When there are, on average, more than 20 anomalies per grid, it is necessary to statistically sample the anomalies. If the anomalies are identified using mag & flag or another geophysical method that does not evaluate of the "quality" of the anomaly (e.g., does not differentiate between anomalies considered more likely to be UXO from anomalies less likely to be UXO), then GridStats software should be used (refer to Chapter 10). On the other hand, when geophysical approaches that discriminate between anomalies are used, UXO Calculator software should be utilized to select anomalies for actual excavation and evaluation.

7-15. Data Interpretation, Resectorization and Decision Making.

a. After a site undergoes an analysis of historical information, is sectorized, sampling grids placed, geophysical sampling performed, and anomalies identified, excavated and evaluated, it is necessary to carefully interpret all the data and determine if project objectives have been met. Original sector boundaries may need to be changed, new sectors may need to be added, and data gaps may exist that must be filled prior to subsequent decisions being made.

b. The geophysical data and evaluations are usually incorporated into a larger study (e.g., EE/CA, Remedial Investigation/Feasibility Study, Site Characterization) and involve project stakeholders who make decisions regarding future work to be performed.

7-16. Geophysical Mapping. After a site has been investigated, characterized and determined to contain unacceptable amounts of UXO, a decision may be made to use geophysical mapping to locate UXO for removal. Unlike geophysical sampling, where only representative portions of the site are investigated, geophysical mapping in support of UXO removal must be performed on 100 percent of the area unacceptably contaminated. Geophysical mapping is performed basically the same way that geophysical sampling is performed. However, geophysical mapping for UXO removal is more rigorous since all possible UXO must be detected and removed.

a. Anomaly Discrimination. Computer-based evaluation is an important tool for interpreting geophysical data. The project team must consider which geophysical tool will be used during the anomaly discrimination process. The project team will ensure that it analyzes the geophysical data and provides hard copy and digital dig-sheets containing, as a minimum, the following pre-excavation information:

(1) Project site;

(2) Grid number;

(3) Anomaly number;

(4) Geophysical contractor;

(5) Responsible field geophysicist;

(6) Date geophysically mapped;

(7) Responsible analyst;

(8) Date geophysically analyzed;

(9) Predicted location coordinates;

(10) Predicted depth to top of item (optional);

(11) Predicted length (optional);

(12) Predicted diameter (optional);

(13) Predicted azimuth (optional); and

(14) Comments.

b. Anomaly Reacquisition and Marking.

(1) Anomaly reacquisition and marking is an extremely important aspect of a UXO geophysical mapping project which often receives inadequate attention. Often, errors resulting from the original positioning during the geophysical survey, data analysis adjustments, and positioning errors during reacquisition combine to yield a reacquired location up to several feet away from the actual anomaly location. The most accurate reacquisition is accomplished using the same instrument used in the geophysical survey to pinpoint the anomaly and reduce the area the excavation team needs to search to find the item.

(2) Discrepancies between original mapped locations of anomalies as shown on the dig-sheet and the actual reacquired location, as well as any anomalies that could not be reacquired, need to be recorded and included in the geophysical report.

c. Anomaly Excavation. After the location of a subsurface anomaly has been marked by the reacquisition team, the anomaly is excavated, identified, and properly disposed. This can be an extremely hazardous activity and should only be undertaken by qualified personnel working under an approved Work Plan. The excavation team must collect pertinent information regarding each anomaly and provide it to the geophysical team. Information to be collected includes, at a minimum, the following post-excavation information:

(1) Project site;

(2) Grid number;

(3) Anomaly number;

(4) Excavation contractor;

(5) Responsible OE Safety Specialist;

(6) Date of excavation;

(7) Actual location coordinates;

(8) Weather conditions;

(9) Anomaly identification (UXO, suspect UXO, ordnance scrap, and scrap);

(10) Actual depth to top of item;

(11) Soil type;

(12) Actual length (Optional);

(13) Actual diameter (optional);

(14) Actual azimuth (optional);

(15) Item material composition (optional); and

(16) Comments.

d. Data Feed-Back. It is important to build a feed-back loop between the geophysicists mapping and analyzing site data and the individuals excavating anomalies and performing field quality control. Comparison of the type of items found in the field to the original data will allow the geophysicists to adjust the processing methodology and reduce the number of false selections. Information such as size, depth, weight and metallic nature (i.e., ferrous vs. non-ferrous) of items found can be useful to geophysicists in directing intrusive teams to the anomalies most likely representing ordnance.

7-17. Digital Data Format and Storage.

a. The project team should develop requirements and standards for a digital data management system tailored for the specific ordnance investigative needs of the project. All geophysical data generated by the project team as well as the data required to associate the geophysical data to its correct geographical location must be generated and stored in a format and media that permits loading, storage, and use on GIS workstations without modification or additional software. The use of an Internet connection should be considered. The geophysical mapping technology should digitally capture the instrument readings into a file coincident with the state grid coordinates. This field data must be checked, corrected and processed into ASCII files. Corrections for navigation, instrument bias, and diurnal magnetic shift should be applied but there should be no filtering or normalization of the data. Any corrections should be documented.

b. Grids geophysically mapped will be exactly coincident with the grid system used by the UXO removal action project team and will use exactly the same datum and coordinate system. The data will be presented in delineated fields using x, y, and z coordinates where x and y are local State Grid Plane Coordinates in East and North and z is the instrument reading. Each of the data fields will be separated by a space (not a comma). There should be no header or other information included in the file. No individual file may be more than four megabytes in size and no more than 60,000 lines long. Each grid of data will be logically and sequentially named so that the file name can be easily correlated with the grid name used by other project personnel. The formats specified in this paragraph must be followed exactly, although the project team may choose to submit the data in additional formats as well.

7-18. Quality Management.

a. Objective. The general objective of geophysical investigations during an OE removal action is to efficiently locate buried UXO so that it can be properly evaluated, recovered and disposed. Specific geophysical investigation objectives of a project are defined by the project team and must be risk-based, measurable, and attainable.

b. General Approach.

(1) On OE projects, there are two elements which are subject to QA/QC: processes and products.

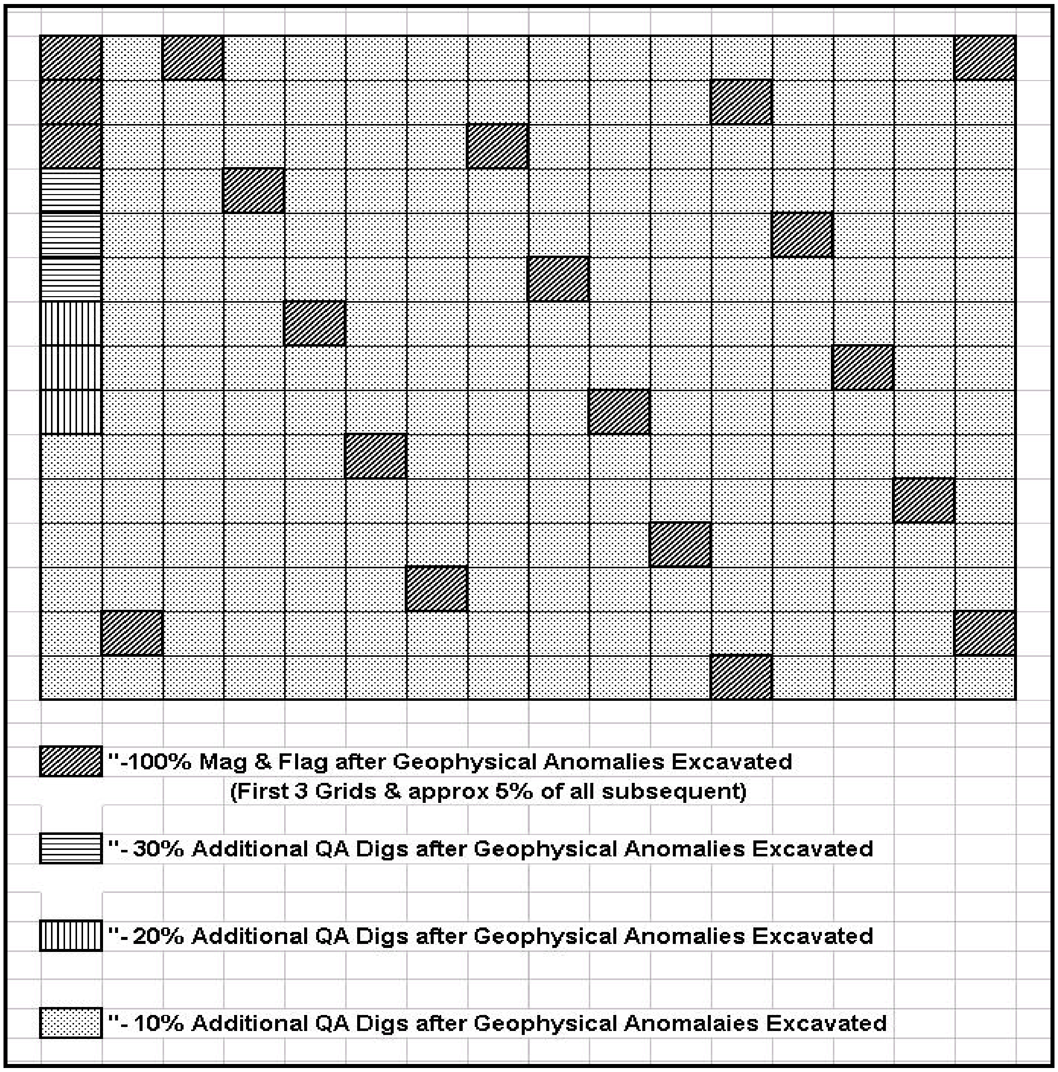
(a) "Processes" are the project-specific geophysical planning and data collection/data analysis procedures and methods that must be performed.

(b) "Products" are the final project-specific deliverables and results that must be achieved.

(2) Both the project processes and the project products must be part of a formal quality management process in order to demonstrate that project quality objectives are met.

c. Process Quality Management. The project team must periodically check the geophysical data provided by the project team to assure positional accuracy, proper instrument calibration, and analysis confirmation.

d. Product Quality Management. This section discusses the process for quality management at OE sites where digital geophysical mapping is used. Figure 7-8 provides an illustration of this process.




Notes:
1. If any of these first three 100% grids fail, then geophysical picking process has not yet been proven adequate for site. Correct problem.
2. For 30%, 20% and 10% grids, field QA may pick additional anomalies for excavation using any method.
3. Grid must have no QA failures in order to step down to next lower QA percentage.
4. If any QA failure occurs, evaluate & correct cause, revert back to 30% QA and step down as described above.
5. After 10% QA level is reached, approx. 5% of all grids should be 100 mag/flag in addition to digital geophysical mapping.
6. A "failure' is defined to be any UXO or inert OE look-alike being found by QA, if within project-defined siz3/depth parameters. Project team may pick alternate "failure" definition.
7. If UXO or inert-OE is found by geophysical mapping or QA that is outside of project parameters, evaluate.
USAESCH 23 June 1999.

Figure 7-8
Quality Management Process at OE Removal Sites Where
Digital Geophysical Mapping Is Used

(1) One hundred percent of all anomalies should initially be removed from three to five grids. The results will be provided to the project geophysicist so that prioritized dig lists can be developed.

(2) The geophysical team will remain available during the entire anomaly removal process. The geophysical team should not perform site mapping and then leave. It is unlikely that the geophysical team can successfully pick anomalies without feedback of actual field data.

(3) Approximately 5 percent of the grids should be randomly selected for 100 percent anomaly removal.

(4) The remainder of the grids should have all suspect anomalies removed, plus 10 percent to 30 percent of additional anomalies dug, depending on the status of the project.

(5) If a grid has very few or very many suspect anomalies, 10 percent to 30 percent additional anomaly excavation may not be feasible. If so, a higher or lower number of QA/QC anomalies may be justified and selected.

# ATTACHMENT 7-1
# GEOPHYSICAL INVESTIGATIONS CHECKLIST

Project Name: ______________________________
Project Location: ______________________________
Design Center POC: ______________________________
Preparer's Name and Title: ______________________________
Date of Preparation: ______________________________

| | Y | N | N/A |
|---|---|---|---|
| **Geophysical Planning Considerations** | | | |
| 1. Is the geophysical planning being performed by or under the supervision of a geophysicist? | ____ | ____ | ____ |
| 2. Have objectives been considered for the geophysical investigation in the following areas: | | | |
| • Geophysical sampling? | ____ | ____ | ____ |
| • Geophysical mapping? | ____ | ____ | ____ |
| • Geophysical interrogation? | ____ | ____ | ____ |
| 3. Has the geophysical investigation planning process addressed: | | | |
| • Experienced personnel? | ____ | ____ | ____ |
| • Geophysical instruments? | ____ | ____ | ____ |
| • Analysis procedures? | ____ | ____ | ____ |
| • Navigational accuracy and precision? | ____ | ____ | ____ |
| **Geophysical Instrument Considerations** | | | |
| 1. Have the following factors which affect geophysical instruments been considered: | | | |
| • UXO composition? | ____ | ____ | ____ |

| | Y | N | N/A |
|---|---|---|---|
| • UXO size? | ______ | ______ | ______ |
| • UXO depth? | ______ | ______ | ______ |
| • UXO fuzing? | ______ | ______ | ______ |
| • Background interference from metallic scrap? | ______ | ______ | ______ |
| • Soil composition and geology? | ______ | ______ | ______ |
| • Vegetation and terrain? | ______ | ______ | ______ |
| • Cultural Features? | ______ | ______ | ______ |

**Selection of Geophysical Instruments**

1. Which type of geophysical instrument is the most appropriate:

| | Y | N | N/A |
|---|---|---|---|
| • Active (conductivity meter)? | ______ | ______ | ______ |
| • Passive (magnetometer or gradiometer)? | ______ | ______ | ______ |

**UXO Detection Rates**

1. Have the following factors been considered in determining the detection rate in the field for a geophysical instrument:

| | Y | N | N/A |
|---|---|---|---|
| • Vegetation? | ______ | ______ | ______ |
| • Terrain? | ______ | ______ | ______ |
| • Geologic noise/Gradients? | ______ | ______ | ______ |
| • Cultural noise? | ______ | ______ | ______ |
| • UXO fragments? | ______ | ______ | ______ |
| • UXO penetration beyond detection? | ______ | ______ | ______ |

**UXO Detection Depths**

| | Y | N | N/A |
|---|---|---|---|
| 1. Have maximum UXO detection depths been estimated in accordance with Tables 7.2 and 7.3? | ______ | ______ | ______ |
| 2. Has the maximum possible depth of UXO at the site been estimated? | ______ | ______ | ______ |

| | Y | N | N/A |
|---|---|---|---|
| **Geophysical Instruments and Electric Fuze Safety** | | | |
| Have the following safety precautions been applied to the project: | | | |
| 1. Passive Instruments: | | | |
| • Are the passive instruments being used in accordance with manufacturer's instructions? | ___ | ___ | ___ |
| 2. Active Instruments: | | | |
| • Prior to using an active instrument, has the operator determined if any fuzing systems exist at the site that contain any electrical components? | ___ | ___ | ___ |
| • If an OE site does not contain electrical fuzes, are the active instruments being used in accordance with manufacturer's instructions? | ___ | ___ | ___ |
| • If an OE site does contain or is reasonably expected to contain electrical fuzes, has the instrument operator submitted a request for a waiver from the Design Center Safety Manager? | ___ | ___ | ___ |
| **Analysis Software** | | | |
| 1. Has the appropriate analysis software been selected for the specific instrument? | ___ | ___ | ___ |
| 2. Prior to using the software, have navigation adjustments been made? | ___ | ___ | ___ |
| 3. Prior to using the software, have the coordinate systems been rotated and translated? | ___ | ___ | ___ |
| **Navigation System** | | | |
| 1. Which type of positional system was selected: | | | |
| • Temporary? | ___ | ___ | ___ |
| • Permanent? | ___ | ___ | ___ |
| 2. Is the navigation system based on the local State Grid Plane system? | ___ | ___ | ___ |

| | Y | N | N/A |
|---|---|---|---|
| **<u>Geophysical Prove-out Planning</u>** | | | |
| 1. Have DQOs been developed? | ______ | ______ | ______ |
| 2. Has a Work Plan been developed for the prove-out? | ______ | ______ | ______ |
| 3. Does the Prove-out Work Plan describe the following: | | | |
| • Prove-out grid location and construction? | ______ | ______ | ______ |
| • Factors influencing prove-out grid location and construction: | | | |
| – Terrain, vegetation, geological conditions? | ______ | ______ | ______ |
| – Proximity to the field site? | ______ | ______ | ______ |
| – Isolation from overhead power lines, radio transmitters, underground utilities, etc? | ______ | ______ | ______ |
| – Convenient access? | ______ | ______ | ______ |
| – Likelihood that the area will be disturbed during use? | ______ | ______ | ______ |
| – Rights-of-Entry? | ______ | ______ | ______ |
| – Possibility of pre-existing buried UXO? | ______ | ______ | ______ |
| • Pre-Seeding geophysical mapping? | ______ | ______ | ______ |
| • Have the following items been considered regarding pre-seeding: | | | |
| – Size and configuration? | ______ | ______ | ______ |
| – Survey accuracy? | ______ | ______ | ______ |
| – Layout? | ______ | ______ | ______ |
| – Seeded items? | ______ | ______ | ______ |
| – Depths and orientations? | ______ | ______ | ______ |
| – Cultural interference? | ______ | ______ | ______ |
| – UXO fragment interference? | ______ | ______ | ______ |

| | Y | N | N/A |
|---|---|---|---|
| • Data collection variables, including: | | | |
| – Instrument height? | ___ | ___ | ___ |
| – Instrument orientation? | ___ | ___ | ___ |
| – Direction of travel? | ___ | ___ | ___ |
| – Measurement interval? | ___ | ___ | ___ |
| – Lane width? | ___ | ___ | ___ |
| • Data analysis and interpretation? | ___ | ___ | ___ |
| • Data evaluation? | ___ | ___ | ___ |
| • Selection of detection instruments? | ___ | ___ | ___ |

**<u>Geophysical Investigation Plan</u>**

| | Y | N | N/A |
|---|---|---|---|
| 1. Does the Geophysical Investigation Work Plan address the following: | | | |
| • Site Description: | ___ | ___ | ___ |
| – Geophysical Investigation Program Objectives? | ___ | ___ | ___ |
| – Specific Area(s) to be Investigated, including a map? | ___ | ___ | ___ |
| – Past, current and future use? | ___ | ___ | ___ |
| – Anticipated UXO type, composition and quantity? | ___ | ___ | ___ |
| – Depth anticipated? | ___ | ___ | ___ |
| – Topography? | ___ | ___ | ___ |
| – Vegetation? | ___ | ___ | ___ |
| – Geologic conditions (including bedrock type, mineralization and depth)? | ___ | ___ | ___ |
| – Soil conditions (including soil type/composition, typical moisture content, and thickness)? | ___ | ___ | ___ |

| | Y | N | N/A |
|---|---|---|---|
| – Shallow groundwater conditions (including depth, mineralization, existence of perched tables, and seasonal & tidal variations)? | ______ | ______ | ______ |
| – Geophysical conditions, including background geophysical gradients? | ______ | ______ | ______ |
| – Site Utilities? | ______ | ______ | ______ |
| – Man-made features potentially affecting geophysical investigations? | ______ | ______ | ______ |
| – Site-specific dynamic events such as tides, unusually strong winds, or other unusual factors affecting site operations? | ______ | ______ | ______ |
| – Overall Site Accessibility and Impediments? | ______ | ______ | ______ |
| – Potential Worker Hazards? | ______ | ______ | ______ |
| • Geophysical Investigation Methods: | | | |
| – Equipment? | ______ | ______ | ______ |
| – Procedures? | ______ | ______ | ______ |
| – Personnel? | ______ | ______ | ______ |
| – Production Rates? | ______ | ______ | ______ |
| – Data Resolution, or line/grid width requirements? | ______ | ______ | ______ |
| – Data density? | ______ | ______ | ______ |
| – Data Processing? | ______ | ______ | ______ |
| • Location Surveying, Mapping and Navigation: | | | |
| – System Description? | ______ | ______ | ______ |
| – If GPS systems are used, correlate satellite availability with work/rest periods? | ______ | ______ | ______ |

| | Y | N | N/A |
|---|---|---|---|
| • Instrument standardization: | | | |
| – Instrument drift? | ____ | ____ | ____ |
| – Standardization procedures? | ____ | ____ | ____ |
| – Abbreviated standardization checks? | ____ | ____ | ____ |
| – Instrument response to a known standard? | ____ | ____ | ____ |
| • Data processing, correction and analysis: | | | |
| – Instrument drift correction? | ____ | ____ | ____ |
| – Diurnal drift correction? | ____ | ____ | ____ |
| – Digital filtering and enhancement? | ____ | ____ | ____ |
| – Correlation with ground truth? | ____ | ____ | ____ |
| • Quantitative interpretation and dig sheet development? | ____ | ____ | ____ |
| • Anomaly reacquisition? | ____ | ____ | ____ |
| • Feed-back process? | ____ | ____ | ____ |
| • Quality control? | ____ | ____ | ____ |
| • Corrective measures? | ____ | ____ | ____ |
| • Records management? | ____ | ____ | ____ |
| • Interim reporting? | ____ | ____ | ____ |
| • Final reports and map? | ____ | ____ | ____ |

**<u>Sectorization</u>**

| | Y | N | N/A |
|---|---|---|---|
| 1. When defining sectors, were the following factors considered: | | | |
| • Former military use? | ____ | ____ | ____ |
| • Anticipated UXO type? | ____ | ____ | ____ |
| • Anticipated UXO distribution? | ____ | ____ | ____ |
| • Terrain and vegetation? | ____ | ____ | ____ |

| | Y | N | N/A |
|---|---|---|---|
| • Current land use? | ______ | ______ | ______ |
| • Natural and cultural boundaries? | ______ | ______ | ______ |

**Sampling within a Sector**

1. Which sampling methodology is appropriate for the sector:

| | | | |
|---|---|---|---|
| • 100% sampling? | ______ | ______ | ______ |
| • Authoritative sampling? | ______ | ______ | ______ |
| • Probability sampling? | ______ | ______ | ______ |
| • If probability sampling is selected, which type of strategy will be used in the sector: | | | |
| – Fixed pattern grid sampling? | ______ | ______ | ______ |
| – Random pattern grid sampling? | ______ | ______ | ______ |
| – Hybrid sampling? | ______ | ______ | ______ |
| – Transect sampling? | ______ | ______ | ______ |
| – Meandering path sampling? | ______ | ______ | ______ |

**Sampling Anomalies within a Grid**

1. Which sampling methodology is appropriate for the grid?

| | | | |
|---|---|---|---|
| • 100% sampling? | ______ | ______ | ______ |
| • Statistical sampling? | ______ | ______ | ______ |

**Data Interpretation**

| | | | |
|---|---|---|---|
| 1. Was the geophysical data interpreted after the geophysical investigation? | ______ | ______ | ______ |
| 2. Were the project objectives met? | ______ | ______ | ______ |

**Geophysical Mapping**

1. Do the dig sheets contain the following information:

| | | | |
|---|---|---|---|
| • Project site? | ______ | ______ | ______ |
| • Grid number? | ______ | ______ | ______ |

| | Y | N | N/A |
|---|---|---|---|
| • Anomaly number? | ______ | ______ | ______ |
| • Name of the geophysical contractor? | ______ | ______ | ______ |
| • Name of the responsible field geophysicist? | ______ | ______ | ______ |
| • Date geophysical mapping occurred? | ______ | ______ | ______ |
| • Name of the responsible analyst? | ______ | ______ | ______ |
| • Date the data was geophysically analyzed? | ______ | ______ | ______ |
| • Predicted location coordinates? | ______ | ______ | ______ |
| • Predicted depth to top of item (optional)? | ______ | ______ | ______ |
| • Predicted length (optional)? | ______ | ______ | ______ |
| • Predicted diameter (optional)? | ______ | ______ | ______ |
| • Predicted azimuth (optional)? | ______ | ______ | ______ |
| • Comments. | ______ | ______ | ______ |
| **<u>Anomaly Reacquisition and Marking</u>** | | | |
| 1. Was the same instrument used for reacquisition as that used in the geophysical survey? | ______ | ______ | ______ |
| 2. Were discrepancies between original mapped locations of anomalies as shown on the dig-sheet and the actual reacquired location recorded and included in the geophysical report? | ______ | ______ | ______ |
| **<u>Anomaly Excavation</u>** | | | |
| 1. Was the following post-excavation information collected: | | | |
| • Project site? | ______ | ______ | ______ |
| • Grid number? | ______ | ______ | ______ |
| • Anomaly number? | ______ | ______ | ______ |
| • Excavation contractor? | ______ | ______ | ______ |
| • Name of the responsible OE Safety Specialist? | ______ | ______ | ______ |
| • Date of excavation? | ______ | ______ | ______ |

| | Y | N | N/A |
|---|---|---|---|
| • Actual location coordinates? | ______ | ______ | ______ |
| • Weather conditions? | ______ | ______ | ______ |
| • Anomaly identification? | ______ | ______ | ______ |
| • Actual depth to top of item? | ______ | ______ | ______ |
| • Soil type? | ______ | ______ | ______ |
| • Actual length (optional)? | ______ | ______ | ______ |
| • Actual diameter (optional)? | ______ | ______ | ______ |
| • Actual azimuth (optional)? | ______ | ______ | ______ |
| • Item material composition (optional)? | ______ | ______ | ______ |
| • Comments. | ______ | ______ | ______ |
| **Digital Data Format and Storage** | | | |
| 1. Were the requirements and standards for a digital data management system tailored for the specific ordnance investigative needs of the project? | ______ | ______ | ______ |
| 2. Has the geophysical data been stored in a format and media that permits loading, storage and use of GIS workstations without modification or additional software? | ______ | ______ | ______ |
| **Quality Management** | | | |
| 1. Were procedures for process quality management followed? | ______ | ______ | ______ |
| 2. Were procedures for product quality management followed? | ______ | ______ | ______ |